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June 21, 2017

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Subject: EPA/ADEQ Comments on March 2017 Decision Tree and Criteria for Enhanced Bioremediation; Transmittal of EPA/ADEQ Checklist for EBR Monitoring Program, ST12 Fuels Spill Site, Former Williams Air Force Base, Mesa, Arizona

Dear Ms. Jerrard:

The US Environmental Protection Agency (EPA) and Arizona Department of Environmental Quality (ADEQ), "the Agencies" joint technical team has reviewed Air Force's (AF's) March 2017 Decision Tree and Criteria for Enhanced Bioremediation ("Decision Tree") for the ST12 Fuels Spill Site, and compared it to the May 2014 Final Remedial Design and Remedial Action Work Plan (RD/RAWP), the March 2016 Draft Final Addendum #2 to the RD/RAWP, and to proposed Phase 1 Enhanced Bioremediation (EBR) activities presented during the May 11, 2017 Base Closure Team (BCT) conference call, along with other data from the site. Although it is still our collective technical opinion that EBR alone cannot reduce the estimated 400,000+ gallons of jet fuel remaining in the subsurface at ST012 to volatile organic compound (VOC) concentrations that will not contaminate groundwater to levels above their Maximum Contaminant Levels (MCLs) in the next 20 years, we understand that it is nevertheless the desire of the Air Force to proceed with EBR at this time. This changes the site remediation discussion from whether or not to proceed with EBR to what the Agencies require for the Air Force to be able to proceed with EBR considering the present condition of the site.

The Agencies have prepared the attached Checklist to provide AF with a list of data needs that should be incorporated into the final EBR workplan to develop a robust monitoring program to enable future evaluation of EBR effectiveness. We also offer the following comments on the March 2017 Decision Tree. Some of these comments reflect concerns that have been expressed previously, and others are new comments.

**General Comments**

1. Page 1 of Decision Tree, fourth box in flowchart says "Monitor baseline conditions", and times this activity to occur after the start-up of extraction activities. Baseline monitoring should occur prior to any EBR-related extractions or injections to provide valid baseline data. Performing this baseline data before any extractions or injections is promised in Section 5.1 of the Addendum #2, Remedial Design and Remedial Action Work Plan for Operable Unit 2, Revised Groundwater Remedy, Site ST012, Former Williams Air Force Base, Mesa, Arizona. Section 5.1 of this document states that: "Prior to EBR injection and extraction activities, sampling will be conducted to determine baseline conditions and to adjust operational strategy based on conditions in the field."

2. A full delineation of the benzene contaminated areas has not been completed in any of the three hydrogeologic units. Without knowing the full extent of the current benzene concentration distributions, it cannot be determined if the plumes continue to migrate or if they are shrinking. Slides from the February 14, 2017 BCT meeting clearly indicate that areas with benzene concentrations in groundwater greater than 5 □g/L have not been fully delineated, as large portions of the 5 □g/L contour line are dashed (indicating the delineation is inferred) in the Cobble Zone (CZ) and Upper Water Bearing Zone (UWBZ), with smaller portions of the contour line being dashed in the Lower Saturated Zone (LSZ).

    a) Observation of the benzene isoconcentration line in the CZ (slide 22) also shows that the downgradient perimeter wells in the CZ are generally 250 feet or more from the SEE wells; thus, any migration of the dissolved phase contaminants in the hydrogeologic unit may not be detected in a timely manner due to the distance to the downgradient monitoring wells. In addition to the lack of benzene plume delineation to the north and east, as shown in slide 23, the extent of the benzene plume to the southwest also may not be defined. According to the data provided in June 2017, CZ22 was last sampled on 10/10/2016, and benzene was less than 1 □g/L. However, the weekly field reports show that 0.66 feet of LNAPL were found in this well on 11/4/2016. Thus, it is not clear that the benzene concentration in this well remains below 5 □g/L (e.g., sample dilution may have caused this low measurement). The boring for LSZ57 had numerous photoionization detector (PID) readings in the range of 40 to 74 parts per million volume (ppmv) from 140 to 160 feet below ground surface. Note that a benzene concentration of 50 ppmv in soil vapor is equivalent to 700 ug/L in groundwater under equilibrium conditions (based on the benzene dimensionless Henry's Law coefficient of 0.23). According to Attachment 4, Locations and Drilling Plan, footnote f of Field Variance #4, Additional Site Characterization, "If PID screening results are >15 ppmv . . . location may not bound dissolved phase contamination." Additional sampling of well CZ22 is needed, and a CZ monitoring well is needed in the area of LSZ57 to verify the extent of the dissolved-phase plume in the CZ in this area.

    b) In the UWBZ, benzene groundwater concentrations in wells UWBZ36 and UWBZ35 are above 5 □g/L, indicating that the extent of the dissolved phase plume exceeding MCLs is not delineated to the west in this hydrogeologic zone. PID readings as high as 50 ppmv in the UWBZ of soil boring LSZ57 raise important questions about the extent of the dissolved phase in that area, considering the fact that this PID value is equivalent to 700 ug/L in groundwater. Recent groundwater concentration data for perimeter monitoring wells U02

(1.7 □g/L on 3/1/2017 and 2.2 □g/L on 4/18/2017) and U38 (0.18 □g/L on 2/6/2017, the first time benzene has been detected in this well) indicate that the line delineating the extent of benzene concentrations above 5 □g/L should be extended significantly to the east in slide 24.

c) Slide 26 shows that the extent of the benzene dissolved-phase plume has not been delineated in the area of SB-19 to the west, in the area of LSZ46 to the south, in the area of SB18 to the southeast, and in the area of W36 to the northeast.

3. A full delineation of the light nonaqueous phase liquid (LNAPL) contaminated areas has not been completed. Without adequate characterization of the LNAPL distribution at ST012, the extent of the areas that require remediation has not been defined. Slides from the March 16, 2017 BCT meeting clearly show that the extent of LNAPL has not been defined: 1) in the UWBZ to the southeast (UWBZ30 area, see slides 17 and 18) and 2) in the LSZ (see slides 20-23) to the southeast in the areas of SB18, to the south in the area of LSZ46, and to the west at SB19. Also, there is a large distance between the borings that contained LNAPL in the UWBZ and LSZ on the northern side of the site (LSZ43 and LSZ51) and the one LNAPL-free boring to the north (LSZ59), creating considerable uncertainty in the extent of LNAPL in this direction.

4. Post- Steam Enhanced Extraction (SEE) characterization is needed within the thermal treatment zone (TTZ) of SEE. The May 2014 Final RD/RAWP states (page 4-9) that the target benzene concentration in the thermal treatment zone is 100 to 500 µg/L, as "This concentration range is predicted to achieve cleanup levels within the 20-year remedial timeframe based on modeling of groundwater contaminant attenuation outside the TTZs after active EBR". However, no groundwater samples have been obtained from within the central portion of the SEE treatment zone since the termination of SEE to determine if this target groundwater concentration was achieved. Samples obtained during SEE are not reliable due to the samples having been obtained from the eductor pumps, which contained both eductor motive water and groundwater. Since the termination of SEE, LNAPL has been recovered from many of these interior wells, indicating the likelihood of very high dissolved-phase and LNAPL benzene concentrations remaining in the TTZ. Discussions between the Air Force team and the agencies' teams have highlighted the fact that there is considerable uncertainty in remaining mass estimates and the modeling performed to date. Additional modeling using an agreed-upon modeling approach and based on new samples taken to evaluate post-SEE soil and groundwater concentrations should be used to determine whether or not the SEE TTZ requires additional treatment, based on post-SEE soil and groundwater concentrations.

5. Soil borings from within the SEE TTZ are also required to allow much more accurate estimates of LNAPL and dissolved-phase hydrocarbon mass, as the current Air Force estimates (dated 9/28/15) assumed apparently arbitrary reductions in each area and zone due to SEE without providing justification based on case study results or post-SEE sampling data (ADEQ letter dated May 16, 2017, to Ms. Catherine Jerrard).

6. An important consideration for the success of EBR will be ensuring that the injected terminal electron acceptor (TEA) is distributed throughout the area of remaining hydrocarbon contamination. The EBR and SEE Containment Modeling Report in Appendix E of the May 2014 Final RD/RAWP states (page 4-1), "This 60-foot well spacing was determined to be optimal by an iterative process using the

groundwater flow model to assess various configurations of the well fields within the geometry of the treatment areas. Beyond an approximate well spacing of 75 feet results from the model revealed that sufficient extraction pumping could not be achieved because of limitations associated with the permeability and storage of the aquifer and subsequent loss of injectate to the natural gradients in these gaps between extraction well capture zones." Despite this modeling result indicating that a 60-foot well spacing is optimal, Addendum #2 and the May 11, 2017 BCT presentation propose injection-extraction well spacings as much as 250 feet or more. Figures E-1, E-8 and E-15 of Addendum #2, which are titled, Modeled TEA Injection Pathlines for the CZ, UWBZ, and LSZ, respectively, show that injected TEA would not be distributed throughout the ovals of Target Area of Sulfate Distribution by Injection-Extraction shown on slides 25 – 27 of the May 11, 2017 BCT presentation, but would travel in relatively narrow paths. Specific examples of discrepancies between the Modeled TEA Injection Pathlines and the Target Area of Sulfate Distribution include the fact the TEA Pathlines show TEA injected at CZ12 to migrate downgradient (Figure E-1), rather than being extracted at CZ21, as suggested by slide 25; Figure E-8 shows TEA injected at UWBZ32 and UWBZ33 to migrate downgradient rather than be captured at UWBZ22 as suggested by slide 26; and Figure E-15 show TEA injected at W34 to migrate downgradient rather than be captured by LSZ29, as suggested by slide 27. It is clear from the TEA Pathline figures that the proposed injection and extraction schemes are not adequate to distribute TEA throughout the contaminated areas.

The Time of Remediation Estimates for Enhanced Bioremediation at ST012 (provided by the Agencies to the Air Force on May 30, 2017) states that the hydraulic conductivity values for the LSZ and UWBZ used in the AF modeling reported in Appendix E are significantly lower than what was used in previous AF modeling. Incorporating more realistic hydraulic conductivities (i.e., based on current field measurements of hydraulic conductivity, such as slug tests) into the model should provide a much more accurate view of the flow of the TEA, either under pumping or non-pumping conditions.

7. It is not clear what sulfate concentrations are ideal for BTEX degradation at the ST012 site, or what concentration may be inhibitory to the microorganisms. The Decision Tree in the first blue box states that sulfate concentrations in the range 2,000 – 10,000 mg/L are ideal for microbial growth, and that concentrations as high as 30,000 mg/L are non-inhibitory, but no justification (either literature or field case studies) is provided for these statements. Suthersan et al. (2011) suggests that maintaining relatively stable sulfate concentrations in the range of 100 to 2000 mg/L increases the efficiency of the process, and that sulfate concentrations greater than 2000 mg/L do not yield increased hydrocarbon oxidation rates. They state, "Dosing strategies that achieve moderate and more consistent concentrations are best to achieve optimum treatment efficiency and limit secondary geochemical effects." Al-Zuhair et al. (2008) found that sulfate concentrations above 4,000 mg/L may begin to inhibit sulfate reduction.

8. Addendum #2 proposes to inject sulfate at a concentration of 320,000 mg/L (March 2016 Addendum #2, page 4-7). After pumping only for a short time during the injection of sulfate to help distribute it, Addendum #2 and the Decision Tree then proposes to terminate extraction and allow the sulfate to distribute by dispersion and diffusion. Addendum #2 provides figures to illustrate the concentrations of a conservative tracer (meant to represent sulfate) injected at a concentration of 320,000 mg/L in each of the three hydrologic zones over the next 1990 days (Figures E-2 to E-7, E-9 to E-14, and E-16 to E-21). These figures show significant migration of sulfate offsite at concentrations greater than the secondary MCL for sulfate of 250 mg/L (Figures E-7 and E-21), and sulfate concentrations high enough to inhibit

microbial growth over large portions of the UWBZ and LSZ 1990 days (approximately five and one half years) after sulfate injection (Figure E-14 and E-21).

Another thing to note on the figures from Appendix E which depict tracer concentrations due to dispersion and diffusion effects, is that these figures predict that it would take as much as 5.5 years (1990 days) for the sulfate concentrations to reach the 1000 mg/L range (where sulfate reduction is maximized) throughout the areas that are believed to contain LNAPL. This situation is not likely to be sufficiently alleviated by the addition of a couple of injection or extraction wells as proposed in the May 11, 2017 BCT presentation.

Per the Decision Tree (page two), microbial analyses would occur 6 to 36 months after the initial sulfate injection, for the purpose of monitoring EBR stimulation. However, if sulfate migration will take as much as 5.5 years to reach the concentrations throughout the areas believed to contain LNAPL, then EBR monitoring needs to occur in areas where sulfate has already reached prime concentrations.

On page 3 of the Decision Tree, top box with the subtitle "Decision Objective: Transition Criteria Achieved?", it is stated that the time frame of these analyses is between 18 and 36 months after the first injection. One of the metrics mentioned is "Sulfate distributed to support ongoing MNA". It is unclear how it can be determined between 18 and 36 months after the first injection if sulfate is correctly distributed (spatially, or at proper concentrations) throughout areas believed to contain LNAPL if this distribution may take up to 5.5 years. The same can be said of the criteria contained in the second box, including benzene half-lives in the three zones, throughout all areas containing LNAPL.


**Specific Comments on Decision Tree**

9. The first yellow box (titled "Decision Objective: To establish location is ready for EBR injections") calls for monitoring LNAPL levels, and that '<1 ft/week' accumulation in a well is "ideal" and '< 5 ft/week' is "non-inhibiting". It is not clear in which wells LNAPL levels will be monitored. LNAPL monitoring in proposed extraction wells was terminated when the pumps were installed as AMEC claims they cannot monitor for LNAPL with the pumps in place. The March 2016 Draft Addendum #2 to the RD/RAWP states on page 4-11, "If mobile LNAPL is observed in a new or existing injection well, the LNAPL will be removed, to the extent practical prior to injections. If sustained recovery of LNAPL is possible, TEA injection at that location will be delayed." This would seem to indicate that LNAPL levels in injection wells is to be monitored.

What is the basis for saying that '<1 ft/week' is "ideal" and '< 5 ft/week' is "non-inhibiting" and EBR should proceed? In the second yellow box of the Decision Tree, it states, "LNAPL removal is generally more efficient than EBR. LNAPL not removed can increase EBR timeframe." This statement belies the implication that LNAPL accumulations of up to 1 ft/week in an injection well are acceptable for proceeding with EBR. Several of the planned injection wells, including CZ11, UWBZ10, UWBZ33, UWBZ16, W11, W37, LSZ50, LSZ48, and LSZ49, have recently and continuously contained LNAPL under non-pumping conditions, and thus are not likely to be useable as injection wells in the immediate future. These wells should be used for LNAPL recovery rather than for EBR.

10. The first yellow box states that if the hydraulic response is not consistent with expectation, then the

distribution (presumably of sulfate) may be affected. What is the expected hydraulic response? What are the planned extraction rates for each extraction well and expected drawdowns in each of the wells?

11. The first yellow box states that if temperatures are changing rapidly at extraction or injection locations, potentially temperature should be monitored and wait for stabilization. This appears to be contradictory to the AF's objections that continuous groundwater extraction for containment would have a negative effect on EBR because such extraction would adversely affect the temperatures that are currently advantageous to EBR, and would pull dissolved oxygen into the system, and thereby alter the redox conditions. The May 2014 Final RD/RAWP that was approved stated "The approach to remediating the LNAPL-impacted zone outside the TTZ combines the technologies of groundwater recirculation with the addition of terminal electron acceptor (TEA), and plume containment." (Section 3.5, first sentence). The description of the EBR design goes on to say "Process equipment will be installed for integrated operations for active remediation and containment of the three hydrologic zones (CZ, UWBZ and LSZ)," and "The overall system will be hydraulically designed to capture and maintain the plume geometry." The EBR and SEE Containment Modeling Report in Appendix E states "The approach to remediating the LNAPL impacted zone outside the TTZ combines the technologies of groundwater recirculation with the addition of terminal electron acceptor (TEA), and plume containment, followed by a period of natural attenuation and groundwater monitoring." Based on the May 2014 Final RD/RAWP, containment was an integral part of the planned EBR. It is not clear why containment was not a part of the Addendum #2 Work Plan.

It should be noted that temperature data provided in Section VI of the April 29 – May 12, 2017 ST012 Site Operations Report shows that virtually all of the area in the three hydrogeologic zones of the site that are proposed for Phase 1 EBR (see slides 25 to 27 of the May 11, 2017 BCT conference call) remain at significantly elevated temperatures, with temperatures as high as 270°F in May 2017. Thus, it is not likely that these areas will be good candidates for initiation of EBR in the near future. Pumping to extract hot groundwater and pull ambient temperature groundwater into the area may increase the rate of cooling and create conditions amenable to EBR more quickly than allowing cooling only by natural groundwater flow.

12. The first gray box (Titled "Decision Objective: To establish when pumping at individual extraction locations should be terminated" ) seems to indicate that sulfate is expected to arrive at the extraction wells 10 weeks to one year after injections start. What is the basis for this rather significant range in travel times expected between injection and extraction wells?

13. The parameters to be monitored in the first blue box (Titled "Decision Objective: To Establish Biological Degradation by Sulfate Reducing Bacteria (SRB) at ST012 and has been Enhanced") must include VOCs in LNAPL. With an estimated 400,000+ gallons of LNAPL remaining in the subsurface at ST012 (AF's estimate dated March 17, 2017), most of the remaining VOCs are in the LNAPL, not dissolved in groundwater. In order to demonstrate that EBR is having the desired effect of overall site remediation, benzene concentrations in the LNAPL (i.e., the major component of site benzene mass) must be measurably and significantly decreasing.

14. The first blue box states "Decreasing VOCs in the presence of sulfate may indicate degradation." While this statement is true, it must be recalled that injection of large volumes of water containing sulfate will definitely dilute VOC concentrations in groundwater, and displace the contaminated

groundwater. This should not be mistaken for degradation. Decreasing VOC concentrations in groundwater should only be considered to indicate degradation after it has been determined that the appropriate biological communities are present and that they are degrading VOCs (including benzene), and the conservative tracer (in the injection fluids) data is used to standardize observed changes in groundwater analytes. Groundwater data from across the site after TEA injection should be used in the evaluation.

15. The first blue box and the final gray box state that "If degradation by SRB cannot be demonstrated after other measures, consider alternate technologies" and lists pump-and-treat and chemical oxidation as the technologies to be evaluated. Neither of these technologies is appropriate for large quantities of LNAPL such as the more than 400,000 gallons of LNAPL that are believed to be at this site. SEE has been found to be effective for LNAPL at this site and should be considered if EBR is not found to be effective.

16. The second blue box and the white box (page 3) list Target Numerical Conditions of average and maximum benzene concentrations in each of the three hydrologic zones that are presented in the modeling in Appendix E of the RD/RAWP. Comments on this modeling exercise have been provided to the Air Force. Discussions between the Air Force team and the Agencies' teams has highlighted the fact that there is considerable uncertainty in AF's modeling effort to date. Additional modeling using an agreed-upon modeling approach should be used to determine whether or not the SEE TTZ requires additional treatment, based on post-SEE soil and groundwater concentrations.
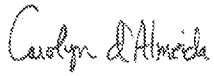
17. The second blue box shows that for the UWBZ, the maximum permissible benzene concentration for transition to Monitored Natural Attenuation (MNA) is 1400 µg/L in groundwater. The May 2014 Final RD/RAWP states on page 4-9 that the target benzene concentrations in the thermal treatment zone is 100 to 500 µg/L, as "This concentration range is predicted to achieve cleanup levels within the 20-year remedial timeframe based on modeling of groundwater contaminant attenuation outside the TTZs after active EBR". Thus, these two criteria appear contradictory. Discussions between the Air Force team and the agencies' teams have highlighted the fact that there is considerable uncertainty in AF's modeling performed to date. Additional modeling using an agreed-upon modeling approach should be used to determine whether or not the SEE TTZ requires additional treatment, based on post-SEE soil and groundwater concentrations.

18. The second yellow box states that the Desired Trend for Sulfate migration is that it not migrate outside of the EBR area. Figure E-4 predicts that sulfate will be migrating out of the EBR area in the CZ within 150 days of injection at wells CZ12, CZ14, and CZ16, and Figure E-7 of Addendum #2 predicts that this will continue for more than 1990 days. Figure E-15 predicts that sulfate injected at W34 will migrate out of the EBR area. This would indicate the need for recirculation/containment throughout EBR. The Agencies are particularly concerned that remedial activities for ST12 must not degrade water quality down gradient of the site that could impact private or City of Mesa supply wells in the future.
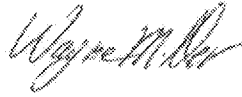
19. The second yellow box states that the Desired Trend for Arsenic Concentrations is "Arsenic concentrations exceed MCLs". The desired trend should be for the arsenic concentrations to not exceed MCLs. Arsenic should not be injected with the sulfate solution at concentrations that exceed the MCLs.

Please contact us if you have any questions about this letter.

Sincerely,

Carolyn d'Almeida
Remedial Project Manager, EPA

Wayne Miller
Remedial Project Manager, ADEQ


cc: Ardis Dickey, AFCEC


References:

Suthersan, S., K. Houston, M. Schnobrich, and J. Horst, Engineered Anaerobic Bio-Oxidation Systems for Petroleum Hydrocarbon Residual Source Zones with Soluble Sulfate Application, Ground Water Monitoring & Remediation, 31(3)41-46, 2001.

Al-Zuhair, S., M.H. El-Naas, and H. Al-Hassani, Sulfate inhibition effect on sulfate reducing bacteria, Journal of Biochemical Technology, 1(2):39-44, 2008.

| Project Stage | General Topic | Specific Metric(s) | Analysis Already Agreed To By USAF? | Timing of Analyses | Frequency of Analyses | Location of Analyses | Purpose | Additional Comments |
|---|---|---|---|---|---|---|---|---|
| Pre-Baseline | | | | | | | These are additional wells to provide accurate monitoring of EBR | |
| | Monitoring Well Installations | | | Before baseline geochemistry, field data, and microbial analyses performed | (Once - is an installation) | (Location of installations) | These MWs are needed to ensure that there are sufficient data to evaluate the effectiveness of EBR. The extraction wells can be used, but must be considered in separate groups and are not sufficient for this evaluation. | MWs are needed in suitable locations to monitor the effectiveness of EBR. Otherwise, data evaluation will be much less meaningful. Accurate delineation of concentrations in downgradient portions of the site should also be emphasized relative to off-site migration potential, sulfate utilization, etc. To the degree possible, wells should also be located so that aquifer heterogeneities (low-permeability zones) can be monitored and accurate spatial averages for parameter values can be computed. New MWs must have time to equilibrate after installation and development before baseline field data, geochemistry, and microbial analyses are performed. |
| | | | | | Once | CZ | | 7 treatment "ovals" proposed, but only 3 ovals have monitoring wells that are in reasonable locations. Monitoring wells should be installed in locations between the injection and extraction wells to evaluate sulfate distribution and EBR progress (5/11/17 BCT slides, slide 25) |
| | | | | | Once | UWBZ | | 5 initial treatment "ovals" proposed; however, only one of the first 5 "ovals" where EBR is proposed for initial implementation has a monitoring well (ST012-UWBZ24). This well is not located in an optimal location for monitoring the effectiveness of treatment (i.e., it is not located on the path between the injection and extraction wells). Since these ovals are proposed for the initial injections, at least one monitoring well should be installed in each oval treatment area so that the injections and EBR progress can be monitored. There are 5 additional treatment "ovals," but there are no monitoring wells in these ovals; monitoring wells should be installed (5/11/17 BCT slides, slide 26) |
| | | | | | Once | LSZ | | 15 treatment "ovals" proposed, but only 2 have monitoring wells in suitable locations. 3 additional "ovals" have monitoring wells located beyond the extraction well. Depending on how the extraction wells are pumped, sulfate may never reach these monitoring wells. Monitoring wells should be installed in locations that are suitable to monitor injections and EBR progress. The wells located beyond the extraction wells should also be monitored to evaluate sulfate distribution (5/11/17 BCT slides, slide 27) |
| | | Continuous logging | Y | during well installation | | Following Table 5.1 | | Taken from Table 5.1, RD-RAWP Addendum 2 (March 2016) |
| | | PID readings | Y | during well installation | | Following Table 5.1 | | Taken from Table 5.1, RD-RAWP Addendum 2 (March 2016) |
| | | LNAPL Dye Test; VOC and TPH if Dye Test is Positive | Y | during well installation | | Following Table 5.1 | | Taken from Table 5.1, RD-RAWP Addendum 2 (March 2016) |
| | | VOCs | Y | | | Following Table 5.1 | To determine if benzene is slower to degrade than other aromatics (or faster, or average) | Taken from Table 5.1, RD-RAWP Addendum 2 (March 2016) |
| | | TPH (DRO, GRO) | Y | | | Following Table 5.1 | | Taken from Table 5.1, RD-RAWP Addendum 2 (March 2016) |
| Baseline Data | | | | | | | To provide one singular, synoptic round of data prior to inception of EBR | These data, collectively, will help establish baseline criteria against which project progress and goals can be compared and monitored. |
| | Hydrogeologic Data | | | After SEE but before EBR injections or amendments | Once as baseline | New and existing MWs, located in the area to be impacted by injections/ amendments, and downgradient of this area | | Data should be acquired for all three zones, including CZ |
| | | Groundwater gauge data (depth to water, depth to product, product thickness) | | | | | For use in modeling | Synoptic measurements should be made to allow accurate development of hydraulic head maps and evaluation of groundwater to produce gw flow directions |
| | | Perform Slug Tests | | | | All New Wells and Existing Wells that have not been tested | Hydraulic Conductivity Measurement; for use in modeling | Data should be acquired for all three zones, including CZ |
| | Mapping Contaminant Locations and Concentrations | | | After SEE but before EBR injections or amendments | Once as baseline | New and existing MWs, located in the area to be impacted by injections/ amendments, and downgradient of this area | | See modeling comments by Bo Stewart, 5/17 |
| | | Continue to locate and map LNAPL presence and depth | Y | | | | | Need to ensure good knowledge of locations where EBR treatments/amendments are being conducted, as well as downgradient |
| | | Monitor benzene content and concentration in LNAPL, where LNAPL is found | Y | | | | Refer notes in "modeling" section of this table. | Need to develop a good baseline of initial NAPL content at locations where EBR treatments/amendments are being conducted, as well as downgradient |
| | | Continue to locate and map dissolved-phase benzene presence and concentration | Y | | monthly | Perimeter wells | | Report (graph) dissolved-phase trends over time, in addition to LNAPL trends for perimeter wells |
| | | Continue to locate and map dissolved-phase VOC presence and concentration | | | | | | |

| Category | Metric | Y | Timing | Frequency | Location/Sampling | Purpose | Comments |
|---|---|---|---|---|---|---|---|
| **Modeling** | Calculate total LNAPL mass present at start of EBR | Y | | | | | ADEQ transmitted extensive comments on the most recent AF mass and composition estimates of remaining NAPL on May 16. |
| | Determine the content of COCs in the LNAPL at the start of EBR | | | | New and existing MWs with recoverable LNAPL | Comparison of NAPL compositions before/during EBR to assess reductions in COC content | The existing characterization of NAPL composition is dated and displays a large deviation in a relatively small set of analyses. The most recent samples were collected from a NAPL holding tank. This NAPL was the combined recovery from the CZ, UWBZ and LSZ with unknown fractions from each. To allow a meaningful comparison of NAPL compositions before/during EBR to assess reductions in COC content, a large set of NAPL samples should be collected and analyzed separately from each zone and across each zone. |
| | Locate and map sulfate concentrations | Y | After SEE but before EBR injections or amendments | Once as baseline | Targeted treatment area and downgradient portions of the site | When compared to this baseline data, this information will help monitor for sulfate migration outside of the COC areas and facilitate comparison of EBR modeling results with field data | |
| | Provide a time estimate for sufficient COCs depletion in LNAPL, groundwater, and soil | | | | | | Please provide a detailed evaluation of important factors determining the efficiency and rate of COC biodegradation and depletion of COCs from the LNAPL source materials. In this evaluation, sensitivity analyses should be incorporated for evaluating the effect of assumptions on remedial efficacy and timeframe scenarios. This will aid in evaluating remedy effectiveness. Please use EPA-team modeled Time of Remediation estimates provided on May 30, 2017 as an example of the detail that should be provided. ST12 Joint agency EBR model cover letter.pdf; TOR Estimates_ST012_052217.pdf; BIONAPL_Box_Model_revised_04-27-2017_UWBZ.xls]. |
| | Provide details of EBR modeling to calculate time estimates for remediation | | | | | | Please use EPA-generated models as an example of sufficient documentation, to allow for an independent evaluation of the results of the modeling. Please see comments provided in: Techlaw memo dated March 24, emailed on April 11, 2017, and Time of Remediation estimates provided on May 30, 2017 (ST12 Joint agency EBR model cover letter.pdf; TOR Estimates_ST012_052217.pdf; BIONAPL_Box_Model_revised_04-27-2017_UWBZ.xls]) |
| | Provide proof of concept supporting the sulfate reduction for EBR | | | | | | In particular, very little field data exists for the CZ and the UWBZ. The AF has not performed the EBR pilot test in the UWBZ that was agreed to in the ST012 Work Plan. |
| | Provide details used to determine the optimal sulfate injection strategy. | | | | | | |
| **GW Geochemistry** | | | After SEE but before EBR injections or amendments | Once as baseline | New and existing MWs, located in the area to be impacted by injections/ amendments, and downgradient of this area | | |
| | Temperature | Y | | | | | |
| | pH | Y | | | | | |
| | ORP value | Y | | | | | Reported on AF flowchart as Eh |
| | Dissolved Oxygen | Y | | | | | |
| | Nitrate | Y | | | | | |
| | Phosphorus | | | | | | |
| | Ferrous Iron | | | | | | AF decision flowchart only mentions "Iron" as an analyte, without differentiating which iron species will be monitored |
| | Total Iron | | | | | | AF decision flowchart only mentions "Iron" as an analyte, without differentiating which iron species will be monitored |
| | Sulfate | Y | | | | | |
| | Hydrogen Sulfide | | | | | | |
| | Methane | | | | | | |
| | Alkalinity | | | | | | |
| | TPH (DRO, GRO) | Y | | | | | |
| | VOCs | Y | | | | | |
| | Arsenic | Y | | | | | |
| **Indigenous Microbial Population** | | | After SEE but before EBR injections or amendments | Once to establish baseline | Samplers should be placed so as to monitor the core of sulfate injections, its periphery, and downgradient. All three zones should be monitored. The same wells should be monitored pre-EBR, during EBR, and post-EBR. | These analyses will quantify the size, makeup, and health of the indigenous microbial community. | All items other than the last metric, and using qPCR to determine the size of the sulfate-reducing population, are included as part of the already-proposed standard stable-isotope probe (SIP; Bio-Trap) study listed on the AF decision flowchart, but are not included in the metrics to be reported. All of these data are key to fully understanding the makeup, activities, and health of the indigenous microbial population. These samplers cannot be used in LNAPL, but can be deployed underneath LNAPL. |
| | Total size | | | | | | |
| | Major groups within population, and their proportion of total | | | | | | |
| | Total size of sulfate-reducing bacteria population | Y | | | | | qPCR performed in addition to the stable-isotope study. AF decision flowchart references SRB gene, but Microbial Insights uses the APS gene to screen for sulfate reducers. Unclear as to what "SRB" gene is being referenced in flowchart. |
| | Total size of benzene-degrading bacteria population | | | | | | |
| | In-situ benzene degradation rate | | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Amount of benzene converted to biomass during stable isotope study | Y | | | | | |
| | | Amount of benzene converted to carbon dioxide during stable isotope study | Y | | | | | |
| | | The overall health of the indigenous microbial population, as determined via PLFA analyses | | | | | | |
| | | The dominant electron-accepting process for indigenous microbial population, and reason for the conclusion | | | | | | |
| **Assessments During EBR** | | | | | | | These assessments will be used to monitor the progress of EBR, and to determine if changes to the EBR strategy need to be made. These will also help monitor progress of EBR. | |
| | **Hydrogeologic Data** | | | | | New and existing MWs, located in the area to be impacted by injections/ amendments, and downgradient of this area | | |
| | | Groundwater gauge data (depth to water, depth to product, product thickness) | | | quarterly | | | Synoptic measurements should be made to allow accurate development of hydraulic head maps and evaluation of groundwater to produce gw flow directions |
| | | Biofouling | Y | | | | | See AF Decision Tree |
| | **Mapping Contaminant Locations and Concentrations** | | | During EBR | | All new and existing MWs, located in the area to be impacted by injections/ amendments, and downgradient of this area | | |
| | | Locate and map LNAPL presence and depth - monitoring wells | Y | | Timing of sampling and analysis to follow schedule outlined in Table 4.1 of referenced document; mapping performed once per month | | | Need to ensure good knowledge of locations where EBR treatments/amendments are being conducted, as well as downgradient. Timing schedule found in: Final Field Variance Memorandum #5 – Extraction and Treatment System Construction, Former Liquid Fuels Storage Area, Site ST012, Former Williams Air Force Base, Mesa, Arizona; 01 Dec 2016 |
| | | Locate and map dissolved-phase benzene presence and concentration | Y | | | | | |
| | | Locate and map dissolved-phase VOC presence and concentration | Y | | | | | |
| | | Calculate total LNAPL mass | | | Quarterly | | | |
| | | Determine the content of COCs in the LNAPL | | | Quarterly | MWs with recoverable NAPL located in the area to be impacted by injections/ amendments | Comparison of NAPL compositions before/during EBR to assess reductions in COC content | Measurements of NAPL content, specifically benzene mole fraction, are a primary parameter for assessing EBR performance. See the "Figures" tab for example plots of benzene mole fraction. Refer to other comments in "modeling" sections of this table. |
| | | Locate and map sulfate concentrations in the targeted treatment area as well as downgradient | Y | | | | | When compared to this baseline data, this information will help monitor sulfate migration outside of the COC areas |
| | **Modeling** | | | During EBR | At least annually | | | |
| | | Provide a time estimate for sufficient COCs depletion in LNAPL, groundwater, and soil | | | | | Demonstrate achievement of remediation goals based on observed benzene concentration reductions in LNAPL and groundwater. Modeling and analyses of field data should also incorporate geochemical (e.g., sulfate) and microbial data (e.g., biomass) parameters that support hydrocarbon mineralization by biodegradation mechanisms (separate from dilution or sorption mechanisms). Modeling needs to evaluate rate-limited dissolution of LNAPL constituents so that the extent to which benzene and other hydrocarbon concentration reductions in groundwater are due to slow NAPL/aqueous-phase mass transfer (refer to example calculations in "Figures" tab). Sensitivity analyses should also be performed to rigorously document the variability of remediation timeframes as a function of EBR parameters. | Please provide a detailed evaluation of important factors determining the efficiency and rate of COC biodegradation and depletion of COCs from the LNAPL source materials. In this evaluation, sensitivity analyses should be incorporated for evaluating the effect of assumptions on remedial efficacy and timeframe scenarios. This will aid in evaluating remedy effectiveness. Please use EPA-team modeled Time of Remediation estimates provided on May 30, 2017 as an example of the detail that should be provided. ST12 Joint agency EBR model cover letter.pdf; TOR Estimates_ST012_052217.pdf; BIONAPL_Box_Model_revised_04-27-2017_UWBZ.xls]. |
| | | Provide details of EBR modeling to calculate time estimates for remediation | | | | | | Please use EPA-generated models as an example of sufficient documentation, to allow for an independent evaluation of the results of the modeling. Please see comments provided in: Techlaw memo dated March 24, emailed on April 11, 2017; and Time of Remediation estimates provided on May 30, 2017 {ST12 Joint agency EBR model cover letter.pdf; TOR Estimates_ST012_052217.pdf; BIONAPL_Box_Model_revised_04-27-2017_UWBZ.xls]} |
| | | Provide proof of concept supporting the sulfate reduction for EBR | | | | | | |
| | | Provide details used to determine the optimal sulfate injection strategy. | | | | | | Ongoing updates as field data become available |
| | **GW Geochemistry** | | | During EBR | Monthly for the first quarter of EBR, followed by quarterly | New and existing MWs | | These analyses will provide an indirect method of monitoring the indigenous microbial community. |
| | | Temperature | Y | | | | | |
| | | pH | Y | | | | | |

| Parameter | Y | During/Frequency | Frequency 2 | Location/Sampling | Purpose/Rationale | Notes |
|---|---|---|---|---|---|---|
| ORP value | Y | | | | | Reported on AF flowchart as Eh |
| Dissolved Oxygen | Y | | | | | |
| Nitrate | Y | | | | | |
| Phosphorus | | | | | To help monitor key microbial nutrient availability | |
| Ferrous Iron | | | | | Will help determine preferred TEA for indigenous microbes | AF decision flowchart only mentions "Iron" as an analyte, without differentiating which iron species will be monitored |
| Total Iron | | | | | Will help determine preferred TEA for indigenous microbes | AF decision flowchart only mentions "Iron" as an analyte, without differentiating which iron species will be monitored |
| Sulfate | Y | | | | To monitor if periodic sulfate injections or recirculation are necessary to sustain degradation rates | |
| Hydrogen Sulfide | | | | | To monitor if hydrogen sulfide concentrations inhibit degradation or will subsurface conditions mitigate their buildup? | |
| Methane | | | | | | |
| Alkalinity | | | | | | |
| TPH (DRO, GRO) | Y | | | | | |
| VOCs | Y | | | | | |
| Arsenic | Y | | | | | |
| **TEA Injection Fluid** | | During EBR, for every injection/ amendment event and location | | | To record makeup and concentration of injection fluid | Taken from Table 5.1, RD-RAWP Addendum 2 (March 2016); This data will provide a record of exactly what was injected, where, and at what concentration. This, when compared with the response by the contaminants and other geochemical and biological data, will help determine if any changes need to be made to amendment variables such as frequency, concentration, etc. |
| ICP Metals | Y | | | | | Any metals over MCL would prevent ability to inject |
| Details of injection material composition | | | | | | This may be proprietary; however, an effort to obtain this information should be made |
| Sulfate | Y | | Monthly, per Table 5.1 Need to check each batch | | | Need to check the TEA fluid before injection fluid before goes into ground to ensure that the concentration is as expected , was mixed and diluted correctly, etc. |
| Location of each injection/amendment | | | | | | |
| Concentration of sulfate at each injection/ amendment location | | | | | | |
| Anticipated zone of influence for each injection/ amendment | | | | | Will the injected sulfate become well distributed with respect to NAPL accumulations? | |
| **Indigenous Microbial Population** | | During EBR, 6-9 months post-injection (per Decision Matrix) | At least once during EBR, 4-6 weeks after initial sulfate injection. May need to be repeated if geochem data suggests a problem. | Samplers should be placed so as to monitor the core of sulfate injections, its periphery, and downgradient. All three zones should be monitored. The same wells should be monitored pre-EBR, during EBR, and post-EBR. | These analyses will quantify the size, makeup, and health of the indigenous microbial community. If there are indications that the microbial population is struggling during EBR, the analyses should be repeated to determine if alternate strategies are needed | All items other than the last metric, and using qPCR to determine the size of the sulfate-reducing population, are included as part of the already-proposed standard stable-isotope probe (SIP; Bio-Trap) study listed on the AF decision flowchart, but are not included in the metrics to be reported. All of these data are key to fully understanding the makeup, activities, and health of the indigenous microbial population. These samplers cannot be used in LNAPL, but can be deployed underneath LNAPL. |
| Total size | | | | | | |
| Major groups within population, and their proportion of total | | | | | | |
| Total size of sulfate-reducing bacteria population | Y | | | | May also help determine lag time for SRBs to acclimate to elevated sulfate concentrations and determine if highly concentrated injections of sulfate will be inhibitive to bacterial activity | Taken from Table 5.1, RD-RAWP Addendum 2 (March 2016). AF decision flowchart references SRB gene, but Microbial Insights uses the APS gene to screen for sulfate reducers. Unclear as to what "SRB" gene is being referenced in flowchart. qPCR performed in addition to the stable-isotope study. |
| Total size of benzene-degrading bacteria population | | | | | | |
| In-situ benzene degradation rate | | | | | | |
| Amount of benzene converted to biomass during stable isotope study | Y | | | | | |
| Amount of benzene converted to carbon dioxide during stable isotope study | Y | | | | | |
| The overall health of the indigenous microbial population, as determined via PLFA analyses | | | | | | |
| The dominant electron-accepting process for indigenous microbial population, and reason for the conclusion | | | | | | |

| Post-EBR Data | | | | | This data will be compared against baseline data, and data taken during EBR, to determine the success of the project as well as to identify necessary future actions. This data will also become the baseline information used at the start of MNA | EBR remedial goals include:<br><br>1) Depletion of COC concentrations (mole fractions) in LNAPL to the degree that the COC-depleted LNAPL cannot transfer COCs to groundwater above MCLs<br><br>2) Reduction of COC concentrations in site groundwater and soil to the degree that MNA could be expected (based on Regulatory Agency-approved modeling) to reduce COCs in groundwater below MCLs within the ROD remedial timeframe.<br><br>Specific numerical metrics, milestones, and timelines (i.e., specific concentrations of COCs in LNAPL and groundwater, along with associated geochemical and microbiological data, at specific times after initial implementation of EBR, and of MNA) will be developed based on Regulatory Agency - approved modeling efforts to guide remedial activities, evaluate success of the remedial approaches, and trigger contingency remedies if necessary. |
|---|---|---|---|---|---|---|
| **Hydrogeologic Data** | | Post-EBR | | Each MW used for injections, amendments, or any analyses | | |
| Groundwater gauge data (depth to water, depth to product, product thickness) | | | Minimum of semi-annual | | | Synoptic measurements should be made to allow accurate development of hydraulic head maps and evaluation of groundwater to produce gw flow directions |
| Biofouling | Y | | once | | To ensure no biofouling after EBR | |
| **Mapping Contaminant Locations and Concentrations** | | Post-EBR | Quarterly, then frequency amended per modeling and EPA guidance on MNA | Each MW used for injections, amendments, or any analyses | | Pope, Daniel F., Steven D. Acree, Herbert Levine, Stephen Mangion, Jeffrey van Ee, Kelly Hurt, Barbara Wilson, Performance Monitoring of MNA Remedies for VOCs in Ground Water EPA/600/R-04/027, National Risk Management Research Laboratory Office Of Research And Development U.S. Environmental Protection Agency, Ada OK, 2004 |
| Locate and map LNAPL presence and depth | | | | | | |
| Locate and map dissolved-phase benzene presence and concentration, in excess of 5 ug/L | | | | | | |
| Locate and map dissolved-phase VOC presence and concentration | | | | | | |
| Calculate total LNAPL mass present | | | | | | Update based on additional field data |
| Determine the content of COCs in the LNAPL | | | | MWs with recoverable NAPL located in the area to be impacted by injections/ amendments | Comparison of NAPL compositions before/during/after EBR to assess reductions in COC content | Measurements of NAPL content, specifically benzene mole fraction, are a primary parameter for assessing EBR performance. See the "Figures" tab for example plots of benzene mole fraction. Refer to other comments in "modeling" sections of this table. |
| Locate and map sulfate concentrations in the targeted treatment area as well as downgradient | Y | | | | | When compared to this baseline data, this information will help monitor sulfate migration outside of the COC areas |
| **Modeling** | | Post-EBR | As needed | | | |
| Provide a time estimate for sufficient COCs depletion in LNAPL, groundwater, and soil by MNA | | | | | Demonstrate achievement of remediation goals based on observed benzene concentration reductions in LNAPL and groundwater. Modeling and analyses of field data should also incorporate geochemical (e.g., sulfate) and microbial data (e.g., biomass) parameters that support hydrocarbon mineralization by biodegradation mechanisms (separate from dilution or sorption mechanisms). Modeling needs to evaluate rate-limited dissolution of LNAPL constituents so that the extent to which benzene and other hydrocarbon concentration reductions in groundwater are due to slow NAPL/aqueous-phase mass transfer (refer to example calculations in "Figures" tab). Sensitivity analyses should also be performed to rigorously document the variability of remediation timeframes as a function of EBR parameters. | Please provide a detailed evaluation of important factors determining the efficiency and rate of COC biodegradation and depletion of COCs from the LNAPL source materials. In this evaluation, sensitivity analyses should be incorporated for evaluating the effect of assumptions on remedial efficacy and timeframe scenarios. This will aid in evaluating remedy effectiveness. Please use EPA-team modeled Time of Remediation estimates provided on May 30, 2017 as an example of the detail that should be provided. ST12 Joint agency EBR model cover letter.pdf; TOR Estimates_ST012_052217.pdf; BIONAPL_Box_Model_revised_04-27-2017_UWBZ.xls]. |
| Provide details of post-EBR modeling to calculate time estimates for remediation | | | | | | |
| **GW Geochemistry** | | Post-EBR | Quarterly, then frequency amended per modeling and EPA guidance on MNA | Each MW used for injections, amendments, or any analyses | | Pope, Daniel F., Steven D. Acree, Herbert Levine, Stephen Mangion, Jeffrey van Ee, Kelly Hurt, Barbara Wilson, Performance Monitoring of MNA Remedies for VOCs in Ground Water EPA/600/R-04/027, National Risk Management Research Laboratory Office Of Research And Development U.S. Environmental Protection Agency, Ada OK, 2004 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Temperature | Y | | | | | |
| pH | Y | | | | | |
| ORP value | Y | | | | | Reported on AF flowchart as Eh |
| Dissolved Oxygen | Y | | | | | |
| Nitrate | Y | | | | | |
| Phosphorus | | | | | | |
| Ferrous Iron | | | | | | AF decision flowchart only mentions "Iron" as an analyte, without differentiating which iron species will be monitored |
| Total Iron | | | | | | AF decision flowchart only mentions "Iron" as an analyte, without differentiating which iron species will be monitored |
| Sulfate | Y | | | | | |
| Hydrogen Sulfide | | | | | | |
| Methane | | | | | | |
| Alkalinity | | | | | | |
| TPH (DRO, GRO) | Y | | | | | |
| VOCs | Y | | | | | |
| Arsenic | Y | | | | | |
| **Indigenous Microbial Population** | | Post-EBR | Once, within 3 months of the last injection/ amendment | Samplers should be placed so as to monitor the core of sulfate injections, its periphery, and downgradient.<br><br>All three zones should be monitored.<br><br>The same wells should be monitored pre-EBR, during EBR, and post-EBR. | These analyses will quantify the size, makeup, and health of the indigenous microbial community at the end of EBR, and will provide baseline data for MNA | All items other than the last metric, and using qPCR to determine the size of the sulfate-reducing population, are included as part of the already-proposed standard stable-isotope probe (SIP; Bio-Trap) study listed on the AF decision flowchart, but are not included in the metrics to be reported. All of these data are key to fully understanding the makeup, activities, and health of the indigenous microbial population.<br><br>These samplers cannot be used in LNAPL, but can be deployed underneath LNAPL. The use of the stable-isotope probes would be anticipated as a one-time event, unless groundwater data suggests a need to perform it again. |
| Total size | | | | | | |
| Major groups within population, and their proportion of total | | | | | | |
| Total size of sulfate-reducing bacteria population | Y | | | | | AF decision flowchart references SRB gene, but Microbial Insights uses the APS gene to screen for sulfate reducers. Unclear as to what "SRB" gene is being referenced in flowchart. qPCR performed in addition to the stable-isotope study. |
| Total size of benzene-degrading bacteria population | Y | | | | | |
| In-situ benzene degradation rate | | | | | | |
| Amount of benzene converted to biomass during stable isotope study | Y | | | | | |
| Amount of benzene converted to carbon dioxide during stable isotope study | Y | | | | | |
| The overall health of the indigenous microbial population, as determined via PLFA analyses | | | | | | |
| The dominant electron-accepting process for indigenous microbial population, and reason for the conclusion | | | | | | |

Example calculations based on scenarios described in "Time of Remediation Estimates, Enhanced Bioremediation at ST012" dated May 22, 2017
Calculation input is provided in Tables 8-10 of the TOR memorandum

Table 8. Parameters for Monod Kinetics

| Parameter | | UWBZ | LSZ | Reference |
|---|---|---|---|---|
| $V_{tot}$ | yd^3 | 122,556 | 38,900 | Table 2 |
| Q | gpm | 4.4 | 3.5 | Table 2 |
| $k_{mass}$ | 1/day | 0.05 | 0.05 | Mobile et al. (2016) |
| $c^{O_2}$ (background) | mg/L | 7.0 | 7.0 | Table M.4.3.2.1 |
| $c^{NO_3}$ (background) | mg/L | 8.0 | 8.0 | Table M.4.3.2.1 |
| $c^{SO_4}$ (background) | mg/L | 200 | 280 | Table M.4.3.2.1 |
| $c^{SO_4}$ | g/g | 4 | 4 | Table M.4.3.5.3 |
| $V^{max}_{benzene,aog}$ | 1/day | 0.000875 | 0.0175 | Table M.4.3.5.1/2 |
| $V^{max}_{toluene,aog}$ | 1/day | 0.031125 | 0.0225 | Table M.4.3.5.1/2 |
| $V^{max}_{ethylbenzene,aog}$ | 1/day | 0.000875 | 0.0175 | Table M.4.3.5.1/2 |
| $V^{max}_{o-xylene,aog}$ | 1/day | 0.031125 | 0.0225 | Table M.4.3.5.1/2 |
| $V^{max}_{m,p-xylene,aog}$ | 1/day | 0.031125 | 0.0025 | Table M.4.3.5.1/2 |
| $V^{max}_{TMB,aog}$ | 1/day | 0.000125 | 0.00125 | Table M.4.3.5.1/2 |
| $V^{max}_{other aromatics,aog}$ | 1/day | 0.030625 | 0.0125 | Table M.4.3.5.1/2 |
| $K^{O_2}_{aog}$ | mg/L | 1 | 1 | Table M.4.3.5.3 |
| $K^{SO_4}_{aog}$ | mg/L | 5 | 5 | Table M.4.3.5.3 |
| Y | g/g | 0.2 | 0.2 | BEM (2007) |
| Mass (initial) | mg/L | 0.01 | 0.01 | BEM (2007) |
| $\lambda^{dec}_{aog}$ | 1/day | 0.001 / 0.0 | 0.001 / 0.0 | BEM (2007) |

Table 9. Initial EBR-Targeted Sulfate Mass and Concentration

| Aquifer Zone | | Calculated^ Target NAPL Volume Porosity=0.3 gal | Calculated^ Target NAPL Volume Porosity=0.4 gal | Literature^ Target NAPL Volume Porosity=0.3 gal | Literature^ Target NAPL Volume Porosity=0.4 gal |
|---|---|---|---|---|---|
| UWBZ V = 122,556 cy | NAPL (gal) = | 250,699 | 235,142 | 284,389 | 596,887 |
| | Sulfate (kg) = | 1,782,067 | 854,629 | 1,218,921 | 1,827,809 |
| | Sulfate (mg/L) = | 36,715 | 23,608 | 43,004 | 43,490 |
| LSZ V = 38,900 cy | NAPL (gal) = | 54,823 | 46,930 | 139,682 | 196,788 |
| | Sulfate (kg) = | 225,415 | 198,211 | 465,106 | 843,554 |
| | Sulfate (mg/L) = | 25,827 | 36,416 | 83,588 | 94,404 |

Table 10. TOR for NAPL Depletion with Sulfate Reduction and Monod Kinetics

| Aquifer Zone | Ambient Flow gpm | Mass Transfer Coeff. day^-1 | Calculated Target NAPL Volume Porosity=0.3 years | Calculated Target NAPL Volume Porosity=0.4 years | Literature Target NAPL Volume Porosity=0.3 years | Literature Target NAPL Volume Porosity=0.4 years | Notes |
|---|---|---|---|---|---|---|---|
| UWBZ | 4.4 | 0.0042 | 133 | 111 | 152 | 178 | 1 |
| UWBZ | 4.4 | 0.05 | 90 | 84 | 102 | 126 | 1 |
| UWBZ | 0.0* | 0.05 | 128 | 116 | 140 | 176 | 2 |
| LSZ | 3.5 | 0.0042 | 52.4 | 36.2 | 104 | 116 | 3 |
| LSZ | 3.5 | 0.05 | 13.2 | 6.4 | 28.0 | 36.1 | 3 |
| LSZ | 0.0* | 0.05 | 12.1 | 8.9 | 27.0 | 27.0 | 4 |



LSZ - Scenario 1



LSZ



LSZ - Scenario 2



LSZ



LSZ - Scenario 3



LSZ